

On the Necessity of Interface Structure in Relational Physical Theories: A Horizons-as-Dynamical-Interfaces Framework (HDIF)

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Abstract

Many modern physical frameworks assign meaning to quantities through relations established in interactions rather than through observer-independent intrinsic properties. This viewpoint appears in multiple settings, including relational interpretations of quantum theory, decoherence-based narratives of record formation, and broader network descriptions of physical information. A recurring but often implicit question then arises: if facts are generated locally within interaction contexts, what determines their coherent comparison across later chains or networks of interactions?

We address this problem in a theory-neutral minimal framework containing three ingredients: interacting systems, locally assigned relational facts, and maps between distinct fact contexts. Within this setting, we prove a minimal interface necessity theorem: local fact assignments together with bare accessibility structure are not, in general, sufficient to determine unique cross-context composition outcomes whenever later comparison, inheritance, or aggregation of records is permitted. Some additional structure specifying admissibility, translation, filtering, compatibility, or equivalence between relational fact spaces is generically required.

We refer to this additional layer as interface structure. The term is used operationally rather than ontologically: no new force, hidden variable, or replacement dynamics is proposed. Instead, the result identifies a structural requirement linking local relationality to global coherence.

This perspective clarifies distinctions that are often blurred in foundational discussions: in relational quantum mechanics, between pairwise fact relativity and observer-chain composition; in decoherence accounts, between redundant record formation and general comparison rules; and more broadly, between accessibility structure and compositional structure. The result is modest in scope but broadly applicable: whenever locally generated facts are later compared across contexts, composition rules become part of the physical description.

1 Introduction: The Composition Problem in Relational Physics

A recurring theme in modern physics is that many quantities acquire physical meaning through relations rather than in isolation. Position is defined relative to a reference frame, velocity relative to chosen coordinates, and gauge descriptions only up to admissible transformations between local representations [1]. In quantum foundations, this relational tendency appears even more sharply in approaches where measurement outcomes or physical facts are treated as context-dependent results of interactions rather than observer-independent attributes of isolated systems.

Such perspectives have substantial explanatory appeal. They weaken the need for naive classical realism, reduce pressure for observer-independent hidden variables, and emphasize that physical description is inseparable from interaction. In particular, relational formulations of quantum theory [2, 3] suggest that what is definite for one system need not yet be definite for another system that has not interacted with it. This move offers a natural response to several longstanding puzzles concerning measurement, state assignment, and observer dependence.

However, relationality introduces a second question that is often left implicit: if facts are established locally through interactions, what determines their coherent comparison across later chains or networks of interactions? Put differently, pairwise relational fact assignments do not by themselves specify how records, outcomes, or effective descriptions should propagate between distinct contexts once further interactions occur.

This issue appears in familiar multi-observer settings. In Wigner-type scenarios [4], one observer may assign a definite outcome while another treats a larger compound system coherently until a later comparison is performed. In decoherence-based accounts [5, 6, 7], environmental monitoring explains suppression of interference and the proliferation of stable records, yet the existence of many local records does not by itself define a general rule for cross-context comparison. More broadly, whenever multiple systems exchange, inherit, compare, or aggregate relational information, a composition problem naturally arises.

The present work studies this problem at a minimal structural level. We ask: what additional ingredients are required for a theory to combine local relational fact formation with later multi-context comparison? Our

central claim is modest but precise: local fact assignments together with bare accessibility structure are not generally sufficient to determine unique cross-context composition outcomes. An additional layer specifying admissibility, translation, filtering, compatibility, or equivalence between relational contexts is generically required.

We refer to this additional layer as *interface structure*. The term is used here in an operational rather than ontological sense. It does not denote a new force, hidden variable, or material boundary. Rather, it denotes whatever further relational data determine when locally established facts may be transmitted, compared, inherited, blocked, or rendered mutually consistent across interacting systems.

The goal of this paper is not to replace quantum mechanics or propose new microphysics. Instead, we formulate a minimal theorem showing that once a theory permits local relational fact assignment together with later cross-context comparison, some interface-like composition structure becomes necessary in general. We then relate this conclusion to relational quantum mechanics, decoherence narratives, gauge patching analogies, and broader network descriptions of physical information.

In this sense, the principal question addressed here is not whether reality is relational, but what additional structure relational descriptions require in order to remain globally coherent.

2 Minimal Definitions

To isolate the composition problem in its simplest form, we introduce a minimal abstract framework. The purpose of these definitions is not to impose new ontology, but to represent the least structure required to discuss relational fact assignment and its propagation across interacting systems.

2.1 Systems

Let $\mathcal{S} = \{S_i\}_{i \in I}$ denote a collection of physical systems. A system may represent a particle, detector, laboratory apparatus, observer, environment, memory register, or any subsystem capable of participating in interactions and carrying state information.

No assumption is made that all systems possess equal descriptive status. The set $\mathcal{S}$ merely indexes nodes in a relational network of possible interactions.

2.2 Interactions

An *interaction event* between two systems S_i and S_j is denoted

$$\mathcal{U}_{ij} : (S_i, S_j) \longrightarrow (S'_i, S'_j),$$

where primes indicate post-interaction states. The symbol $\mathcal{U}_{ij}$ is intentionally general: it may represent measurement, scattering, information exchange, entangling dynamics, coarse-grained environmental coupling, or any physical process through which systems become mutually correlated.

We do not assume that every pair of systems interacts, nor that interactions commute in time or order.

2.3 Relational Facts

A *relational fact* is a fact established relative to an interaction context between systems. We denote such a fact by

$$F_{ij} \in \mathcal{F}_{ij},$$

where $\mathcal{F}_{ij}$ is the set of admissible facts associated with the pair (S_i, S_j) .

Examples include:

- a detector S_j records spin-up relative to particle S_i ,
- system S_j registers arrival time relative to source S_i ,
- two systems become correlated in a specified basis,
- a memory register stores a pointer state relative to an apparatus.

The notation F_{ij} does not imply symmetry: in general,

$$F_{ij} \neq F_{ji}.$$

Different systems may encode different effective descriptions of the same interaction history.

2.4 Fact Assignment Maps

We write

$$\Phi_{ij} : \mathcal{U}_{ij} \longrightarrow \mathcal{F}_{ij}$$

for the rule by which an interaction event gives rise to a relational fact. This may be deterministic, stochastic, coarse-grained, or theory-dependent. The present paper does not specify the microscopic form of Φ_{ij} ; it assumes only that local interactions can generate local fact assignments.

2.5 Geometry Structure

Let $\mathcal{G}$ denote the background accessibility structure specifying which systems may interact or exchange signals. Depending on context, $\mathcal{G}$ may encode:

- spacetime adjacency,
- causal accessibility,
- communication graph connectivity,
- experimental reachability,
- allowed coupling topology.

Thus $\mathcal{G}$ determines which interactions are kinematically or causally possible, but not by itself how relational facts compose once interactions occur.

2.6 Interface Maps

An *interface map* is additional relational structure governing the admissibility of fact transfer, comparison, inheritance, or consistency between distinct interaction contexts.

We denote such a map by

$$I_{(ij) \rightarrow (jk)} : \mathcal{F}_{ij} \longrightarrow \mathcal{F}_{jk},$$

or more generally,

$$I_{\alpha \rightarrow \beta} : \mathcal{F}_{\alpha} \longrightarrow \mathcal{F}_{\beta},$$

where α, β label different relational contexts.

Operationally, an interface map may encode:

- basis translation,
- record comparison rules,
- admissible coarse-graining,
- filtering or loss of inherited information,
- synchronization constraints,
- consistency conditions across observer chains.

The key point is that interface maps do not create local facts; they govern whether and how previously established facts may participate in later relational descriptions.

2.7 Composition Paths

Given multiple interactions, one may attempt to propagate relational information along a chain such as

$$(S_i, S_j) \rightarrow (S_j, S_k) \rightarrow (S_k, S_\ell).$$

A corresponding fact-composition path takes schematic form

$$F_{ij} \xrightarrow{I_{(ij) \rightarrow (jk)}} F_{jk} \xrightarrow{I_{(jk) \rightarrow (k\ell)}} F_{k\ell}.$$

Whether such propagation is well-defined, unique, order-independent, or even admissible is precisely the problem studied in the following sections.

2.8 Minimal Scope

These definitions introduce only three structural layers:

1. systems capable of interaction,
2. locally assigned relational facts,
3. interface maps governing cross-context composition.

No claim is made that these layers are fundamental constituents of nature. They are minimal analytic objects introduced to study whether relational fact assignment alone is sufficient for global consistency.

3 Examples from Relational Quantum Mechanics and Decoherence

The definitions of the previous section are intentionally theory-neutral. We now illustrate how the composition problem arises within two prominent approaches to quantum foundations: relational quantum mechanics and decoherence-based descriptions. The purpose of these examples is not to criticize either framework, but to identify a common structural question: how do locally established facts become consistently comparable across extended chains of interaction?

3.1 Relational Quantum Mechanics: Pairwise Definiteness and Observer Chains

In relational quantum mechanics (RQM) [2, 3], physical properties are not taken as absolute attributes of isolated systems. Instead, values become definite relative to specific interactions between systems. A detector may register a spin value relative to a particle; an observer may later register a detector reading relative to the detector; a second observer may subsequently interrogate the first observer or the combined laboratory.

Within the notation of Section 2, suppose systems S_A , S_B , and S_C interact sequentially. Let:

- S_A be a measured system,
- S_B be a local detector,
- S_C be an external observer.

An interaction $\mathcal{U}_{AB}$ may generate a relational fact

$$F_{AB} \in \mathcal{F}_{AB},$$

such as a definite detector outcome relative to (S_A, S_B) .

Later, a distinct interaction $\mathcal{U}_{BC}$ may generate

$$F_{BC} \in \mathcal{F}_{BC},$$

representing the external observer's later registration of the detector state.

Nothing in pairwise relational assignment alone guarantees that F_{AB} and F_{BC} are automatically identical descriptions, or even directly comparable objects. They belong to different relational contexts:

$$\mathcal{F}_{AB} \neq \mathcal{F}_{BC}$$

in general. A rule is therefore required specifying when the earlier fact may be inherited, translated, coarse-grained, revised, or embedded into the later context.

This is precisely the role of an interface map:

$$I_{(AB) \rightarrow (BC)} : \mathcal{F}_{AB} \longrightarrow \mathcal{F}_{BC}.$$

Without some such structure, one may consistently state that facts are interaction-relative, but the composition of facts across observer chains remains underdetermined.

3.2 Wigner-Type Extensions

The same issue becomes sharper in Wigner-type scenarios [4]. A friend inside a laboratory interacts with a system and records a definite outcome, while an external observer may describe the larger composite laboratory system coherently until a later comparison is performed.

The present paper does not require adopting any particular interpretation of such experiments. The relevant point is structural: one local fact assignment and one external description may coexist until a later interaction compares them. At that comparison stage, a nontrivial interface problem appears:

- Which records are admissible inputs to the later comparison?
- At what level of coarse-graining are prior facts inherited?
- Is composition path-dependent?
- Which descriptions are jointly consistent after interaction?

These are interface questions rather than merely pairwise fact questions.

3.3 Decoherence: Redundant Records Without a General Composition Rule

Decoherence-based accounts explain how environmental coupling suppresses interference between macroscopically distinct branches of a system’s reduced description [5, 6]. Through repeated interactions with many environmental degrees of freedom, information about preferred states may become redundantly encoded across fragments of the environment [7].

Let S denote a system, and let $\{E_k\}$ denote environmental fragments. Repeated interactions

$$\mathcal{U}_{SE_k}$$

can generate families of local relational facts

$$F_{SE_k} \in \mathcal{F}_{SE_k}.$$

This explains why many observers probing different fragments may recover stable effective records. However, redundancy alone does not constitute a universal composition law. Several additional questions remain structural:

- When do two fragments encode the “same” fact?
- How much distortion or coarse-graining is admissible?
- How are incompatible fragment records reconciled?
- How does order of access affect inherited descriptions?
- Which summaries are preserved under later global interactions?

These questions again concern mappings between relational contexts:

$$I_{(SE_i) \rightarrow (SE_j)}, \quad I_{(SE_i) \rightarrow (OE_i)}, \quad I_{\text{local} \rightarrow \text{global}},$$

rather than the mere existence of local correlations.

3.4 Common Structural Lesson

RQM emphasizes relational definiteness through interaction. Decoherence emphasizes environmental proliferation of stable records. These are distinct

programs with different motivations, yet both naturally generate multi-context fact networks rather than a single absolute ledger.

Once multiple contexts exist, a second layer of structure becomes relevant: rules governing when facts may be transferred, compared, merged, blocked, or regarded as equivalent across contexts.

In the notation introduced earlier, local fact assignment maps

$$\Phi_{ij} : \mathcal{U}_{ij} \rightarrow \mathcal{F}_{ij}$$

are not, in general, sufficient to determine multi-context consistency. Interface maps

$$I_{\alpha \rightarrow \beta} : \mathcal{F}_{\alpha} \rightarrow \mathcal{F}_{\beta}$$

become necessary whenever later interactions compare or inherit prior relational records.

3.5 Transition to the Theorem

These examples motivate the central claim of the paper. If a theory permits:

1. locally generated relational facts, and
2. later comparison across multiple systems or contexts,

then some additional composition structure is required in general. The next section formalizes this statement as a minimal theorem.

4 Minimal Interface Necessity Theorem

The previous sections introduced a theory-neutral framework for relational fact assignment and illustrated how composition questions arise naturally in multi-system settings. We now state the central result of the present work in a minimal and interpretation-neutral form.

4.1 Statement of the Problem

Suppose a physical theory permits interactions between systems that generate locally meaningful relational facts. Further suppose that the same theory

permits later processes in which distinct systems compare, inherit, aggregate, or otherwise use records established in earlier interactions.

The central question is whether the following data are sufficient, in general, to determine such later cross-context outcomes:

1. source-like data specifying locally relevant state content or records, and
2. geometry-like data specifying accessibility, adjacency, causal reachability, or interaction topology.

We show that these ingredients are not generally sufficient.

4.2 Theorem (Minimal Interface Necessity)

Let $\mathcal{S} = \{S_i\}$ be a collection of systems endowed with accessibility structure $\mathcal{G}$. Let local interactions generate relational facts

$$F_{ij} \in \mathcal{F}_{ij}$$

through fact-assignment maps

$$\Phi_{ij} : \mathcal{U}_{ij} \longrightarrow \mathcal{F}_{ij}.$$

Assume that the theory admits at least one nontrivial multi-context comparison process in which facts originating in distinct relational contexts may later be jointly queried, compared, inherited, merged, or operationally combined.

Then, in general, the data consisting only of:

1. local fact assignments $\{\Phi_{ij}\}$, and
2. accessibility structure $\mathcal{G}$,

do not uniquely determine cross-context composition outcomes.

Therefore an additional layer of structure is required specifying admissibility, translation, filtering, equivalence, or compatibility between relational fact spaces

$$\mathcal{F}_\alpha, \mathcal{F}_\beta.$$

We denote any such additional structure by an *interface map*

$$I_{\alpha \rightarrow \beta} : \mathcal{F}_\alpha \longrightarrow \mathcal{F}_\beta.$$

4.3 Interpretation

The theorem is intentionally modest. It does not claim that interface maps are new particles, forces, hidden variables, or microscopic mechanisms. Rather, it states that once a theory allows both:

1. local relational fact formation, and
2. later cross-context comparison,

some further rule is generally required to determine how previously established facts participate in later relational descriptions.

Thus interface structure enters not by metaphysical preference, but by compositional necessity.

4.4 Minimal Scope

The theorem does not assert:

- that all physical theories must be relational,
- that interfaces are ultimate constituents of nature,
- that standard quantum mechanics is empirically incomplete,
- that a unique interface map exists,
- that the required structure must be fundamental rather than effective.

It asserts only that whenever relational locality is combined with later multi-context comparability, additional composition structure is generically required.

4.5 Transition

The proof sketch and immediate consequences are given in the following section. There we show explicitly how underdetermination arises already in the minimal three-system case, and why path dependence and binary insufficiency follow naturally once interface maps are introduced.

5 Proof Sketch and Consequences

We now justify the theorem constructively. The aim is not to provide a maximally abstract mathematical proof, but to exhibit the minimal mechanism by which underdetermination arises once locally assigned relational facts are later compared across distinct contexts.

5.1 Proof Sketch: The Three-System Case

Consider three systems

$$S_A, \quad S_B, \quad S_C.$$

Suppose an initial interaction between S_A and S_B generates a relational fact

$$F_{AB} \in \mathcal{F}_{AB},$$

through a local assignment map

$$\Phi_{AB} : \mathcal{U}_{AB} \longrightarrow \mathcal{F}_{AB}.$$

Later, a second interaction between S_B and S_C generates

$$F_{BC} \in \mathcal{F}_{BC},$$

through

$$\Phi_{BC} : \mathcal{U}_{BC} \longrightarrow \mathcal{F}_{BC}.$$

Now consider a later process in which S_C is asked to evaluate, compare, or inherit information involving the earlier AB interaction. Examples include:

- whether the two records agree,
- what S_C should infer about the earlier AB event,
- whether F_{AB} and F_{BC} encode the same effective outcome,
- what summary description should be passed to a later system S_D .

The crucial point is that

$$\mathcal{F}_{AB} \neq \mathcal{F}_{BC}$$

in general. These fact spaces correspond to distinct relational contexts.

Bare accessibility data in $\mathcal{G}$ may specify that A can influence B , and B can later influence C , but it does not specify:

- how facts in $\mathcal{F}_{AB}$ are translated into $\mathcal{F}_{BC}$,
- whether all prior information is preserved,
- whether coarse-graining is required,
- how conflicts are resolved,
- what equivalence relation defines “the same fact.”

This underdetermination can be exhibited explicitly.

Explicit Minimal Example. To make the underdetermination concrete, suppose the earlier interaction between S_A and S_B yields the local fact

$$F_{AB} = \text{“spin-up recorded”},$$

while the later interaction between S_B and S_C establishes that a record exists,

$$F_{BC} = \text{“detector registered”}.$$

Assume the same accessibility structure $\mathcal{G}$ in both cases: A can influence B , and B can later communicate with C .

Now consider two illustrative interface maps, each compatible with the same local records but preserving different levels of inherited detail.

- **Map A (lossless inheritance):**

$$I_{(AB) \rightarrow (BC)}^{(1)}(F_{AB}) = \text{“spin-up recorded”}.$$

The specific outcome is preserved.

- **Map B (coarse-grained inheritance):**

$$I_{(AB) \rightarrow (BC)}^{(2)}(F_{AB}) = \text{“detection occurred”}.$$

Only the existence of a detection event is retained.

Both maps are compatible with the same local facts and identical interaction topology, yet they yield different cross-context summaries. Hence the local assignment maps $\{\Phi_{ij}\}$ together with $\mathcal{G}$ do not uniquely determine composition outcomes.

Therefore cross-context composition is underdetermined unless an additional map is supplied:

$$I_{(AB) \rightarrow (BC)} : \mathcal{F}_{AB} \longrightarrow \mathcal{F}_{BC}.$$

More generally, one requires maps

$$I_{\alpha \rightarrow \beta}$$

between relational contexts. Hence local assignments together with accessibility structure are generically insufficient for unique cross-context composition. $\square$

5.2 Consequence I: Path Dependence

Suppose facts are propagated through multiple intermediate contexts:

$$\mathcal{F}_\alpha \rightarrow \mathcal{F}_\beta \rightarrow \mathcal{F}_\gamma.$$

Then composition takes the form

$$I_{\beta \rightarrow \gamma} \circ I_{\alpha \rightarrow \beta}.$$

If interface maps do not commute or if intermediate filtering is nontrivial, then

$$I_{\beta \rightarrow \gamma} \circ I_{\alpha \rightarrow \beta} \neq I_{\alpha \rightarrow \gamma}.$$

Accordingly, final summaries may depend on the order of interactions or on the route through relational space. Even when each local step is well-defined, global outcomes may be history-dependent.

5.3 Consequence II: Binary Insufficiency

Many frameworks implicitly organize variables into two broad classes:

1. source-like variables, carrying state content or records,

2. geometry-like variables, specifying accessibility or causal structure.

The theorem shows that this binary partition is generically incomplete whenever cross-context fact comparison is allowed. In such settings, one must additionally specify how relational records are admissibly transferred, merged, filtered, or compared.

This motivates a third operational sector: interface structure.

5.4 Consequence III: Effective vs Fundamental Interfaces

The theorem does not require interface maps to be fundamental laws. Several possibilities remain open:

- **Fundamental:** interface structure is basic.
- **Emergent:** interface maps arise after coarse-graining.
- **Contextual:** different regimes possess different interfaces.
- **Approximate:** interface rules hold only in limited domains.

The theorem constrains necessity of function, not ontological status.

5.5 Consequence IV: Relation to Physical Narratives

Different physical programs may realize interface structure in different ways:

- decoherence through environment-mediated record transfer,
- relational quantum mechanics through observer-chain comparison rules,
- gauge theory through transition functions between local descriptions,
- network systems through synchronization or consensus protocols.

The present result is compatible with multiple realizations. It identifies the shared structural role rather than endorsing one microscopic implementation.

5.6 Minimal Lesson

Once a theory allows local relational facts together with later comparison across contexts, composition rules cease to be optional bookkeeping. They become part of the physical description.

In this sense, interface structure is not an embellishment added after the fact. It is the minimal bridge between local relationality and global coherence.

5.7 Transition

Having established the generic necessity of interface structure, we next compare this conclusion with existing approaches in quantum foundations, gauge patching, and broader relational formalisms.

6 Relation to Existing Frameworks

The theorem developed above is intentionally structural rather than polemical. It does not seek to displace established approaches in quantum foundations, gauge theory, or network science. Instead, it isolates a recurring question that often appears implicitly across multiple domains: once locally valid descriptions exist, what additional structure governs their admissible composition across contexts?

This section situates the present result relative to several existing frameworks.

6.1 Relational Quantum Mechanics

Relational quantum mechanics (RQM) [2, 3] emphasizes that physical properties are not absolute attributes of isolated systems, but become definite relative to interactions between systems. This perspective removes the need for a universal state of affairs shared identically by all observers at all times.

The present theorem is compatible with that relational move. It addresses a different layer of structure: once facts are interaction-relative, what governs their later comparison across observer chains?

In this sense, the theorem may be viewed as complementary to RQM:

- RQM emphasizes *local fact relativity*,

- the present work emphasizes *cross-context fact composition*.

No criticism of RQM is required for this distinction. Even within a relational ontology, composition maps may still be needed whenever multiple relational records are later compared. Related branching or relative-state responses to multi-observer consistency questions also appear in Everettian approaches [8].

6.2 Decoherence and Quantum Darwinism

Decoherence explains [5, 6] how environmental entanglement suppresses interference between macroscopically distinct alternatives in reduced descriptions. Related programs such as quantum Darwinism [7] emphasize redundant proliferation of stable records across environmental fragments.

These frameworks successfully explain why many observers often recover robust effective classical information. The present theorem addresses a narrower but distinct question: redundancy of records does not, by itself, define a universal rule for translating or comparing all relational records across arbitrary contexts.

Thus decoherence may supply one important physical mechanism for emergent interface structure, especially in open systems. But the abstract role of interface maps is logically broader than any specific decoherence model.

6.3 Gauge Theory and Transition Functions

Gauge theories provide a useful mathematical analogy [1]. Local descriptions defined on overlapping coordinate patches need not coincide globally without transition functions specifying how fields are related across overlaps.

Schematically,

$$\text{local patch A} \xrightarrow{\text{transition}} \text{local patch B}.$$

The present theorem suggests an analogous structure for relational fact spaces:

$$\mathcal{F}_\alpha \xrightarrow{I_{\alpha \rightarrow \beta}} \mathcal{F}_\beta.$$

The claim is not that quantum facts literally form gauge bundles. Rather, the analogy illustrates a common lesson: local validity does not automatically imply global composability.

6.4 Quantum Information and Channels

Modern quantum information theory [10, 11] often represents state updates, noise, and measurement through completely positive trace-preserving maps, instruments, and communication channels.

Such tools already formalize transmission and transformation of information between subsystems. The present work is consistent with these methods. Its contribution is more abstract: it highlights that whenever theories discuss relational records rather than only state vectors, some channel-like composition layer becomes conceptually necessary. In favorable cases, interface maps may be realized concretely as quantum channels, coarse-graining maps, or effective update rules.

6.5 Network and Consensus Systems

Distributed systems, sensor networks, and consensus protocols [12] provide non-quantum examples where local records alone do not guarantee global consistency. Additional synchronization rules are required to reconcile partial information, delays, incompatible encodings, or order-dependent updates.

These systems show that the composition problem is not unique to quantum foundations. It is a generic feature of multi-agent relational descriptions. The present theorem therefore belongs to a wider class of results concerning local data and global consistency.

6.6 General Relativity and Causal Structure

In relativistic settings [9], spacetime geometry constrains which systems can interact and in what causal order. Such geometry determines accessibility structure $\mathcal{G}$ in the sense used earlier.

However, causal reachability alone does not specify how records established in one context are to be interpreted in another context once communication becomes possible. Geometry can determine whether comparison may occur, but not always how comparison should be composed.

Thus geometry-like structure and interface structure play distinct logical roles.

6.7 Novelty and Scope of the Present Result

The contribution of the present work is structural rather than dynamical. No new force law, hidden-variable model, or replacement formalism for quantum mechanics is proposed. Instead, the novelty lies in isolating a distinction that is often used implicitly but seldom stated explicitly as a general requirement.

Many existing frameworks emphasize one or both of the following layers:

1. **Local fact generation:** how outcomes, records, or effective descriptions arise within particular interaction contexts;
2. **Accessibility structure:** which systems may interact, communicate, or stand in causal relation.

The present paper argues that a third layer must be distinguished whenever locally established facts are later compared across contexts:

3. **Cross-context composition structure:** rules governing admissibility, translation, filtering, compatibility, inheritance, or equivalence between relational fact spaces.

The central result of the paper is to show that this third layer is not merely optional bookkeeping in the generic case. Once a theory permits both local relational fact assignment and later multi-context comparison, local assignments together with bare accessibility relations do not generally suffice to determine unique global comparison outcomes.

Accordingly, the paper’s novelty is the explicit formulation and justification of *interface structure* as a logically distinct compositional sector linking local relationality to global coherence.

Whether this sector is fundamental, emergent, approximate, or theory-specific is left open. The present claim is narrower: it should be recognized, modeled, and evaluated as an independent ingredient whenever relational descriptions are extended beyond isolated pairwise interactions.

6.8 Compatibility Rather Than Competition

Because the theorem is structural, it can coexist with multiple deeper ontologies:

- realist or anti-realist interpretations,

- wavefunction realism or epistemic views,
- relational or observer-independent pictures,
- fundamental or emergent spacetime programs.

Different programs may disagree about what ultimately exists while still requiring some effective interface structure whenever locally established records are later composed.

6.9 Transition

Having situated the theorem relative to existing approaches, we next state explicit limits and non-claims in order to avoid overinterpretation of the result.

7 Limits and Non-Claims

The theorem established in this paper is intentionally narrow in scope. It identifies a generic structural requirement linking local relational fact assignment to later multi-context comparison. It does not attempt to settle broader interpretational disputes in quantum mechanics, nor does it propose a new microphysical dynamics. The present section states explicit limits in order to prevent overextension of the result.

7.1 Not a Replacement for Quantum Theory

Nothing in the theorem modifies the predictive formalism of standard quantum mechanics [13]. No alteration is made to Hilbert-space structure, unitary evolution, measurement postulates, Born-rule probabilities, or experimentally verified state-update procedures.

The result concerns a compositional layer of description, not replacement of existing successful mathematics.

7.2 Not a Hidden-Variable Proposal

Interface maps are not introduced here as hidden variables carrying pre-existing outcomes. They need not determine measurement results in advance, restore classical realism, or encode inaccessible microscopic states.

An interface map specifies only how facts already established in one relational context may be translated, filtered, inherited, or compared within another context.

7.3 Not a Proof of Relational Interpretations

The paper does not prove that relational quantum mechanics, QBist views, or other interaction-centered interpretations are correct. It asks only what additional structure would be generically required *if* one adopts frameworks in which facts are locally established relative to contexts and later compared across contexts.

Accordingly, the theorem is conditional rather than doctrinal.

7.4 Not a Claim That Interfaces Are Ultimate Ontology

The term *interface* is used operationally throughout this work. It does not imply that interfaces are the final constituents of reality, that matter reduces to boundaries, or that all physics is fundamentally network mediation.

The theorem establishes necessity of function, not necessity of substance.

7.5 Not Necessarily Fundamental

Even where interface structure is required, it need not be fundamental. Several possibilities remain open:

- effective coarse-grained update rules,
- emergent environmental synchronization,
- context-dependent comparison procedures,
- thermodynamic record-selection mechanisms,
- information-theoretic consistency constraints.

The theorem is compatible with any of these realizations.

7.6 No Uniqueness Claim

The result does not imply that a single universal interface map exists. Different physical regimes may employ distinct admissibility rules, and multiple mathematically valid composition structures may model the same effective situation.

Thus the theorem concerns existence of additional structure, not uniqueness of implementation.

7.7 No Faster-Than-Light Synchronization

Nothing in the theorem requires superluminal communication, instantaneous global updates, or violations of relativistic causality. Interface maps may operate entirely within ordinary causal propagation and delayed comparison processes.

The need for composition structure should not be confused with a need for acausal coordination.

7.8 No Immediate Experimental Signature

The present work is primarily conceptual. By itself, the theorem does not yield a new numerical constant, cross section, or laboratory anomaly. It clarifies structural conditions under which local relational descriptions can be extended to globally coherent comparison schemes.

Any experimental consequences would arise only after specifying concrete physical realizations of interface maps.

7.9 Dependence on Idealized Definitions

The formalism introduced earlier uses abstract sets of systems, fact spaces, and maps between contexts. These objects are simplified analytic tools rather than literal exhaustive descriptions of physical laboratories or conscious observers.

Consequently, the theorem should be read as a structural result within an idealized modeling language.

7.10 What the Paper Does Claim

Within these limits, the core claim remains:

Whenever a theory combines locally generated relational facts with later multi-context comparison, local fact assignments and bare accessibility relations are generically insufficient by themselves. Some additional composition structure is required.

That claim is modest, but nontrivial.

7.11 Transition

With scope and limits clarified, we may now summarize the broader significance of the result and the directions it suggests for future foundational work.

8 Conclusion

This paper has examined a simple but frequently implicit question in relational descriptions of physics: if facts are established locally through interactions, what additional structure is required for such facts to remain coherently comparable across later chains or networks of interactions?

To study this question, we introduced a minimal framework containing three ingredients:

1. systems capable of interaction,
2. relational facts generated within local contexts,
3. maps governing admissible composition between distinct fact contexts.

Within this setting, we established a minimal interface necessity theorem: local fact assignments together with bare accessibility structure are not, in general, sufficient to determine unique cross-context composition outcomes whenever later comparison of records is allowed. Some additional rule specifying translation, filtering, compatibility, inheritance, or equivalence is generically required.

We referred to this additional layer as *interface structure*. The term was used operationally rather than ontologically. No claim was made that interfaces are new particles, hidden variables, or ultimate constituents of nature. Instead, the claim was structural: once a theory permits both

relational locality and later multi-context comparison, composition rules become part of the physical description.

This perspective helps clarify several existing programs without opposing them. In relational quantum mechanics, it distinguishes local fact relativity from the separate problem of observer-chain composition. In decoherence-based narratives, it distinguishes redundant record formation from general cross-context translation rules. In gauge theory, it echoes the broader lesson that locally valid descriptions do not automatically assemble into globally coherent ones without transition data.

The result is intentionally modest. It does not replace quantum mechanics, settle the measurement problem, or determine the ultimate ontology of reality. Its purpose is narrower: to isolate a recurring logical gap that often remains implicit when local relational descriptions are extended to global narratives.

Several future directions follow naturally. Interface maps may be formalized using category-theoretic composition laws [11], quantum channels, network consistency protocols, or concrete open-system dynamics. Distinct interpretations of quantum theory may then be compared according to how explicitly and successfully they realize the required composition layer.

At minimum, the present work provides a compact vocabulary for separating three distinct questions that are often conflated:

1. How are local facts generated?
2. Which systems can later interact?
3. How are locally generated facts consistently composed?

Even if no deeper unification follows, maintaining this distinction may sharpen future discussions in quantum foundations and relational physics.

In that sense, the principal conclusion of this paper is straightforward: local relationality alone does not guarantee global coherence. Whenever facts are later compared across contexts, some interface structure is required.

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